LARGE HIGGS MASS AND $\mu - e$ UNIVERSALITY

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In the limit of very large Higgs mass the Weinberg model becomes non-renormalizable, and this, in principle, provides for an upper limit on the Higgs mass. In actual fact, without further speculation, no useful limit emerges. Instead one is led to speculations on direct lepton hadron interactions violating $\mu - e$ universality. The experimental evidence on this point is considered.

In a recent paper [1] we argued that there is an upper limit to the mass of the Higgs scalar in the Weinberg model. Furthermore some remarks were made on the possibility of breakdown of $\mu - e$ universality at relatively low energies. In response several authors [2] have presented other arguments also leading to an upper limit to the Higgs mass. These articles add a valuable argument to the discussion[†], but the approach is somewhat different, and we will try to spell out our point of view m this matter.

Consider the Weinberg model [3] of weak and e.m. interactions. It contains a Higgs particle interacting with the leptons and vector bosons. This model is (apart from anomalies) renormalizable. Now let us remove the Higgs particle. We then get Glashow's 1961 $SU_2 \times U_1$ model [4] containing neutral currents (as presumably observed) and the well known weak mixing angle. In other words, it contains precisely that what various experiments have shown to exist. We have no way to decide, on experimental grounds, between Glashow's model (vector boson masses put in by hand) and the Weinberg model (vector boson masses generated by the Higgs mechanism).

However, Glashow's model is non-renormalizable. This is not merely a mathematical defect, but it also leads in principle to real physical consequences, Glashow's model cannot be true to arbitrarely high energies, because else the radiative corrections would become very large, and we would have seen them. Thus there exists a cut-off A above which Glashow's model must necessarily become invalid. New physics must come in. Whether this is the Higgs system, or something else is another question. The first thing is to determine Λ, from experiment.

This then is what we tried to do. Due to what we called the screening theorem this turned out to be extremely difficult if we consider experimental data at low energies.

Next we argued as follows. Consider the Weinberg model, and let the Higgs mass become very large. Indeed, certain radiative corrections grow with growing Higgs mass, but one must go to either fantastic high Higgs mass or fantastic high precision before anything like an experimental test becomes possible. However, we also observed that for large Higgs mass perturbation theory breaks down, within the Weinberg model. This latter was also noted in the above quoted articles, on the basis of different arguments. From this however one cannot derive an upper limit on the Higgs mass, at least not without further speculation. Indeed, suppose that perturbation theory in the Weinberg model breaks down. So what! Do we reject quantum chromodynamics because perturbation theory breaks down? Certainly not.

Then we reasoned as follows. If the Higgs sector becomes a strongly interacting system then it may happen that low lying bound states come into existence. From the experimental absence of such states we could then deduce an upper limit on the Higgs mass *if* we were capable of computing the mass spectrum of a strongly interacting system. We *speculated* that the Higgs mass should not become so large that low lying masses would become conceivable, and that gave the upper limit that we quoted. Obviously, due to the lack of a complete theory no one can really fix this upper limit precisely. For this reason all kinds of

[†] Their arguments lead to the statement that radiative corrections for the WWW vertex could be large if both energy and Higgs mass are large with respect to the W-mass.

ingeneous methods to improve the bound by this or that amount are not very meaningful. In particular, the unitarity limit, which is used in the limit of large energy (even large with respect to the Higgs mass) has no practical content. The problem is either to find a radiative correction that is measurable at energies less than the Higgs mass, and that is furthermore sensitive to this mass, or else to derive the consequences at low energy of a breakdown of perturbation theory. There is some hope that in e^+e^- annihilationinto W^+W^- at 200—300 GeV the radiative corrections become sufficiently large to be measurable; this has not yet been calculated. Ideally, either one finds the Higgs particle below 300 GeV or one determines its mass from the radiative corrections at 300 GeV e^+e^- experiments if its mass is larger than 300 GeV. As yet this is only a speculation.

However, also another speculation was given. Imagine that the Higgs mass is so large that perturbation theory breaks down. Perhaps some of the expected low energy phenomena are contained in the usual strongly interacting particles, the hadrons. We have no way of computing properties of the hadrons in this respect, but nonetheless there is one outstanding feature about the Higgs system, and indeed any system that is to cancel the infinities of Glashow's model, and that is the breakdown of μ—e universality. We therefore suggested to be attentive for such effects.

Let us now consider the question of μ—e universality. What is the most that can be tolerated on the basis of present data? Consider a direct coupling of the type $\lambda(\bar{\mu}\mu)X$ where X stands for the hadrons. The e-hadron coupling is supposed to be down by a factor m_e/m_μ. First, if this μ-hadron coupling is scalar or pseudo scalar then we get for λ a limit of about 10^{-3} from K^0-decays. In fact, $K_s \to \mu\mu/K_s \to \pi\pi < 0.3 \times 10^{-6}$ is the relevant number. For forces with the appropriate quantum numbers, $\eta \to \mu^+\mu^-$ is an even more sensitive test. Secondly, let us consider a vector or axial vector coupling. For definiteness we may take X to be a *p*-meson. Thus in addition to the usual electromagnetic couplings we assume the existence of an effective interaction $\rho_\mu(\bar{\mu}\gamma^\mu(\lambda_v + \lambda_a\gamma^5)\mu)$. It turns out that such an interaction can be quite easily accommodated within the present data, in fact the data favour such an interaction with λ_v of the order 10^{-2} to 10^{-3}. For instance, possibly a breakdown in μ—e universality has been observed suggesting a destructive interference of such a term with the usual e.m. interaction in elasti μ—p scattering [5]. Further, in ρ-decay into $\mu\mu$ and ee there is a long standing discrepancy, suggesting roughly a 20% constructive interference for the muon channel. This is what one would expect since the photon propagator has the opposite sign. It must be noted however that none of these effects are experimentally very significant. This holds also for the deviations found in $\phi(1020)$ decay.

For the rest the effects of such an interaction are too small to have been observed. This holds for inelasti μ-scattering, the anomalous magnetic moment of the muon, muonic atoms, or the μ—π atom formation in $K_{\mu 3}$, for values of λ that would produce the above mentioned effects.

As a general conclusion we can say that direct μ-hadron interactions with a coupling strength of order 10^{-2} to 10^{-3} are not forbidden by any experiment. Especially vector type interactions may be observable through interference with e.m. interactions.

Now it is far from clear to us how such interactions would arise from the Higgs system. Nevertheless in our opinion one should remain open-minded on this issue, because the whole Higgs system is up to now a theoretical construction without experimental foundation. And for large Higgs mass we have simply no theoretical predictions because perturbation theory breaks down. Qualitative features such as breakdown of μ—e universality may survive and serve as identification.

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